CSc 372

Comparative Programming Languages

22 : Prolog — Lists

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Introduction

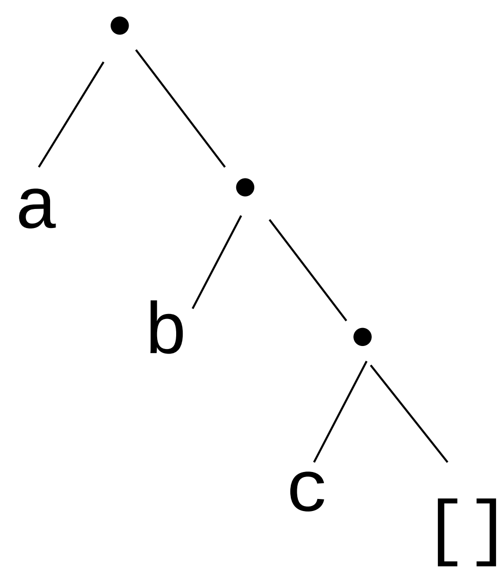
Prolog Lists

Haskell:

```
> 1 : 2 : 3 : []
[1,2,3]
```

Prolog:

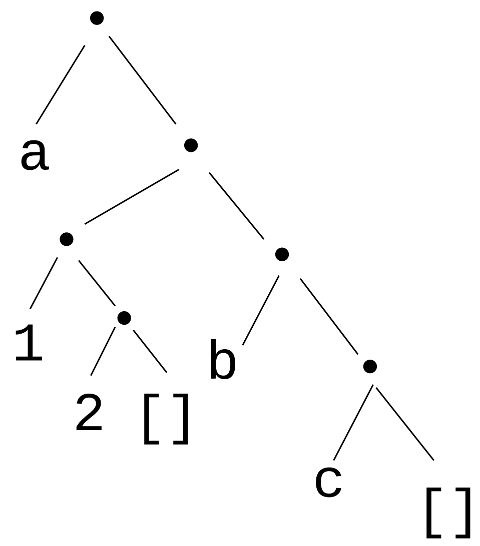
```
?- L = .(a, .(b, .(c, [])))
     L = [a, b, c]
```



- Both Haskell and Prolog build up lists using cons-cells.
- In Haskell the cons-operator is `:`, in Prolog `.`.

Prolog Lists. . .

```
?- L = .(a, .(.(1, .(2, [])), .(b, .(c, []))))
      L = [a, [1, 2], b, c]
```



- Unlike Haskell, Prolog lists can contain elements of arbitrary type.

Matching Lists – `[Head | Tail]`

A	F	$A \equiv F$	variable subst.
`[]`	`[]`	yes	
`[]`	`a`	no	
`[a]`	`[]`	no	
`[[]]`	`[]`	no	
`[a | [b, c]]`	`L`	yes	`L=[a,b,c]`
`[a]`	`[H | T]`	yes	`H=a, T=[]`

Matching Lists – `[Head | Tail]`...

A	F	$A \equiv F$	variable subst.
`[a, b, c]`	`[H | T]`	yes	`H=a,T=[b,c]`
`[a, [1, 2]]`	`[H | T]`	yes	`H=a, T=[[1, 2]]`
`[[1, 2], a]`	`[H | T]`	yes	`H=[1,2], T=[a]`
`[a, b, c]`	`[X, Y, c]`	yes	`X=a, Y=c`
`[a, Y, c]`	`[X, b, Z]`	yes	`X=a, Y=b, Z=c`
`[a, b]`	`[X, c]`	no	

Member

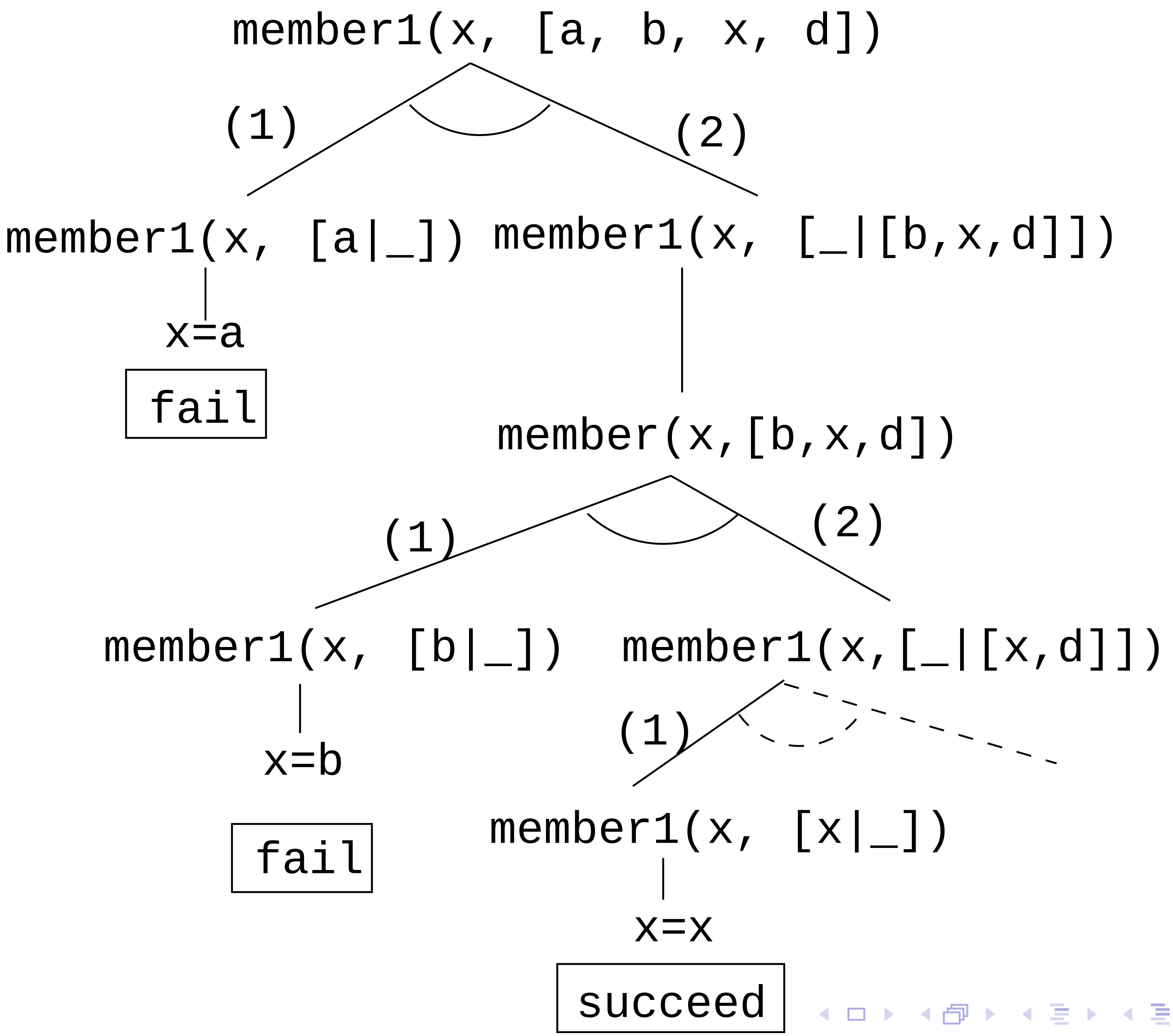
Prolog Lists — Member

```
(1)    member1(X, [Y|_]) :- X = Y.
(2)    member1(X, [_|Y]) :- member1(X, Y).

(1)    member2(X, [X|_]).
(2)    member2(X, [_|Y]) :- member2(X, Y).

(1)    member3(X,[Y|Z]) :- X = Y; member3(X,Z).
```

Prolog Lists — Member...

```
?- member(x, [a, b, c, x, f]).
       yes

?- member(x, [a, b, c, f]).
       no

?- member(x, [a, [x, y], f]).
       no

?- member(Z, [a, [x, y], f]).
       Z = a
       Z = [x, y]
       Z = f
```

Prolog Lists — Member. . .



Append

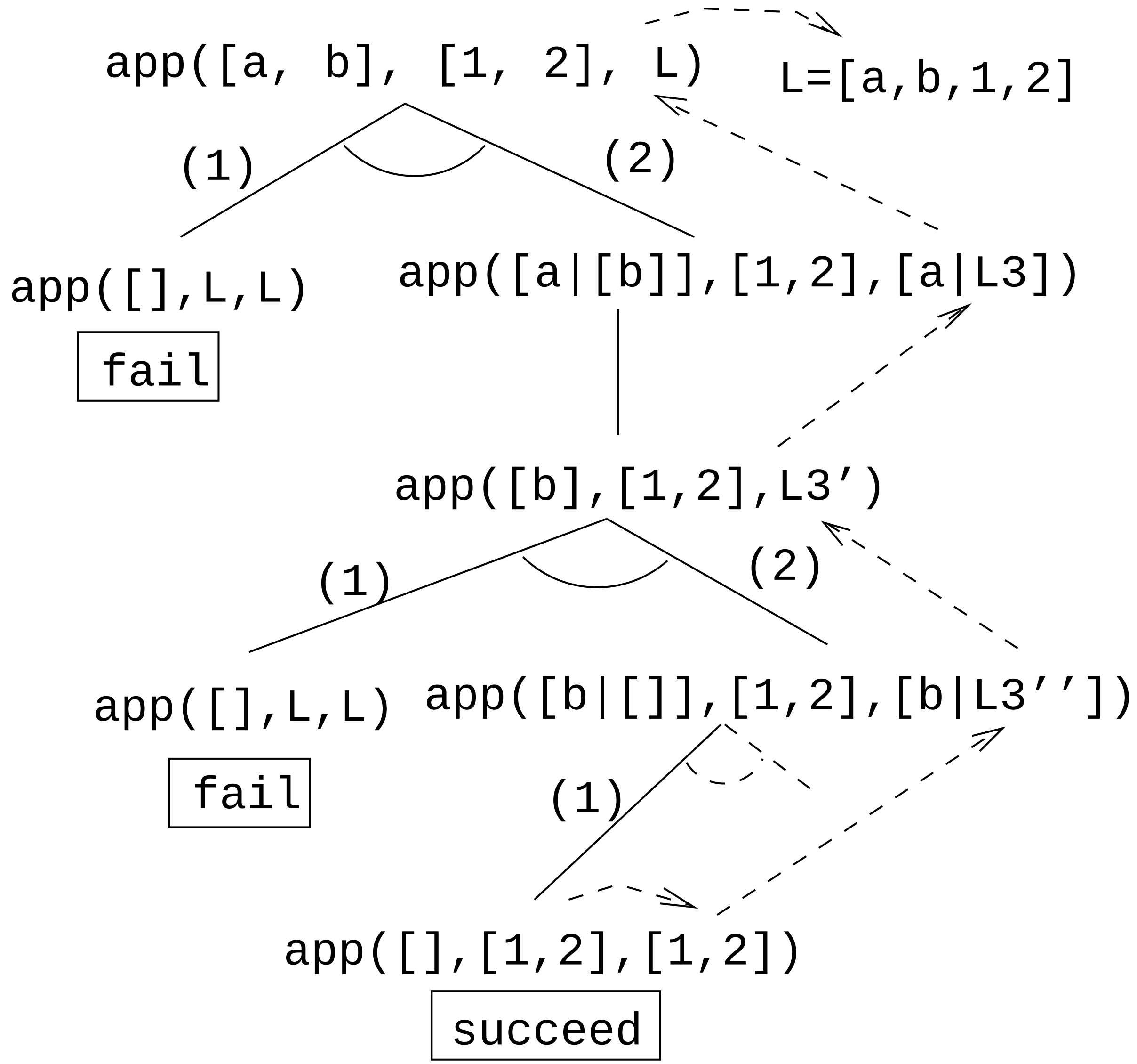
Prolog Lists — Append

```
                followed by    makes
  this one      this one       this one

append(L1, L2, L3).
```

```
(1) append([], L, L)
(2) append([X|L1], L2, [X|L3]) :-
        append(L1, L2, L3).
```

1. Appending L onto an empty list, makes L.
2. To append L_2 onto L_1 to make L_3
    1. Let the first element of L_1 be the first element of L_3.
    2. Append L_2 onto the rest of L_1 to make the rest of L_3.

Prolog Lists — Append. . .



Prolog Lists — Append. . .

```
L=[a,b,1,2]

app([a, b], [1, 2], L)

app([a|[b]],[1,2],[a|L3])

app([b]|[]],[1,2],[b|L3'])

app([],[1,2],[1,2])
```

```
?- L = [a | L3], L3 = [b | L3'], L3' = [1,2].
      L = [a,b,1,2], L3 = [b,1,2], L3' = [1,2]
```

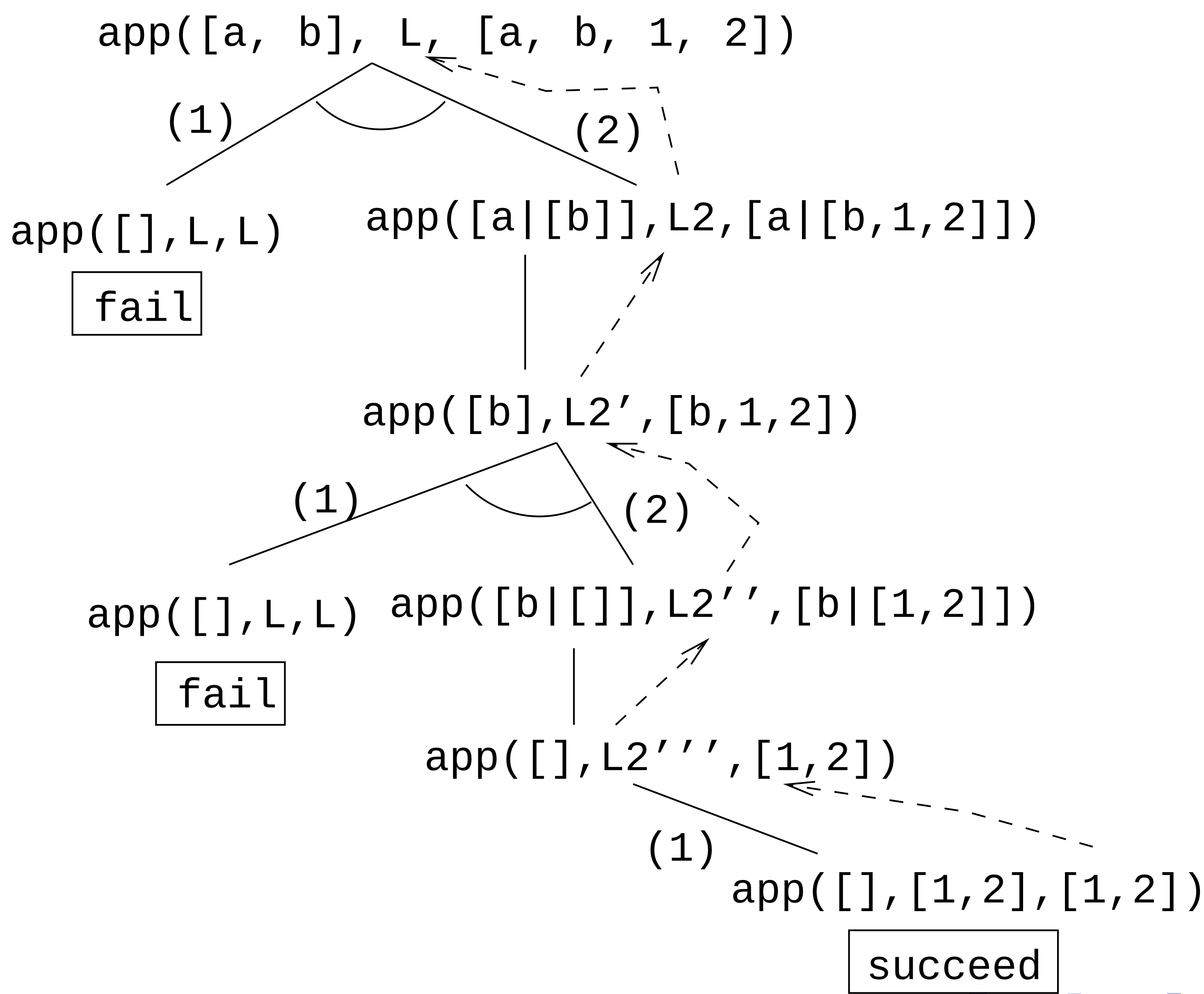
Prolog Lists — Using Append

1. `append([a,b], [1,2], L)`
   - What's the result of appending `[1,2]` onto `[a,b]`?
2. `append([a,b],[1,2],[a,b,1,2])`
   - Is `[a,b,1,2]` the result of appending `[1,2]` onto `[a,b]`?
3. `append([a,b], L, [a,b,1,2])`
   - What do we need to append onto `[a,b]` to make `[a,b,1,2]`?
   - What's the result of removing the prefix `[a,b]` from `[a,b,1,2]`?

Prolog Lists — Using Append. . .

4. `append(L, [1,2], [a,b,1,2])`
   - What do we need to append `[1,2]` onto to make `[a,b,1,2]`?
   - What's the result of removing the suffix `[1,2]` from `[a,b,1,2]`?
5. `append(L1, L2, [a,b,1,2])`
   - How can the list `[a,b,1,2]` be split into two lists L1 & L2?

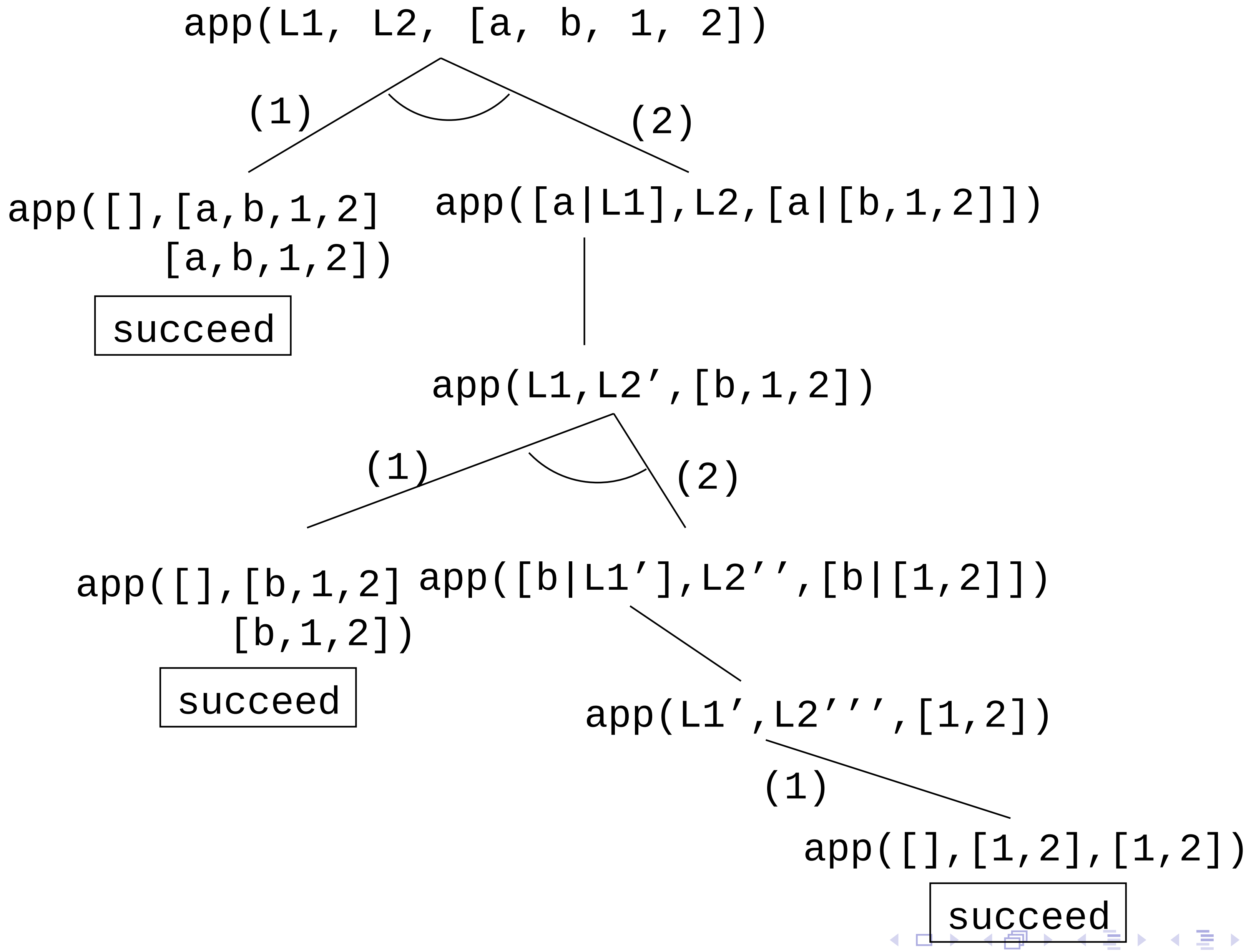
Prolog Lists — Using Append. . .



Prolog Lists — Using Append...

```
?- append(L1, L2, [a,b,c]).
      L1 = []
      L2 = [a,b,c] ;

      L1 = [a]
      L2 = [b,c] ;

      L1 = [a,b]
      L2 = [c] ;

      L1 = [a,b,c]
      L2 = [] ;

      no
```

Prolog Lists — Using Append...



Prolog Lists — Reusing Append

member Can we split the list Y into two lists such that X is at the head of the second list?

adjacent Can we split the list Z into two lists such that the two element X and Y are at the head of the second list?

last Can we split the list Y into two lists such that the first list contains all the elements except the last one, and X is the sole member of the second list?

Prolog Lists — Reusing Append...

```
member(X, Y) :- append(_, [X|Z], Y).
    ?- member(x,[a,b,x,d]).

adjacent(X, Y, Z) :- append(_, [X,Y|Q], Z).
    ?- adjacent(x,y,[a,b,x,y,d]).

last(X, Y) :- append(_, [X], Y).
    ?- last(x, [a,b,x]).
```

Reversing a List

Prolog Lists — Reverse

- `reverse1` is known as *naive reverse*.
- `reverse1` is *quadratic* in the number of elements in the list.
- From *The Art of Prolog*, Sterling & Shapiro pp. 12-13, 203.
- Is the basis for computing LIPS (Logical Inferences Per Second), the performance measure for logic computers and programming languages. Reversing a 30 element list (using naive reverse) requires 496 reductions. A reduction is the basic computational step in logic programming.

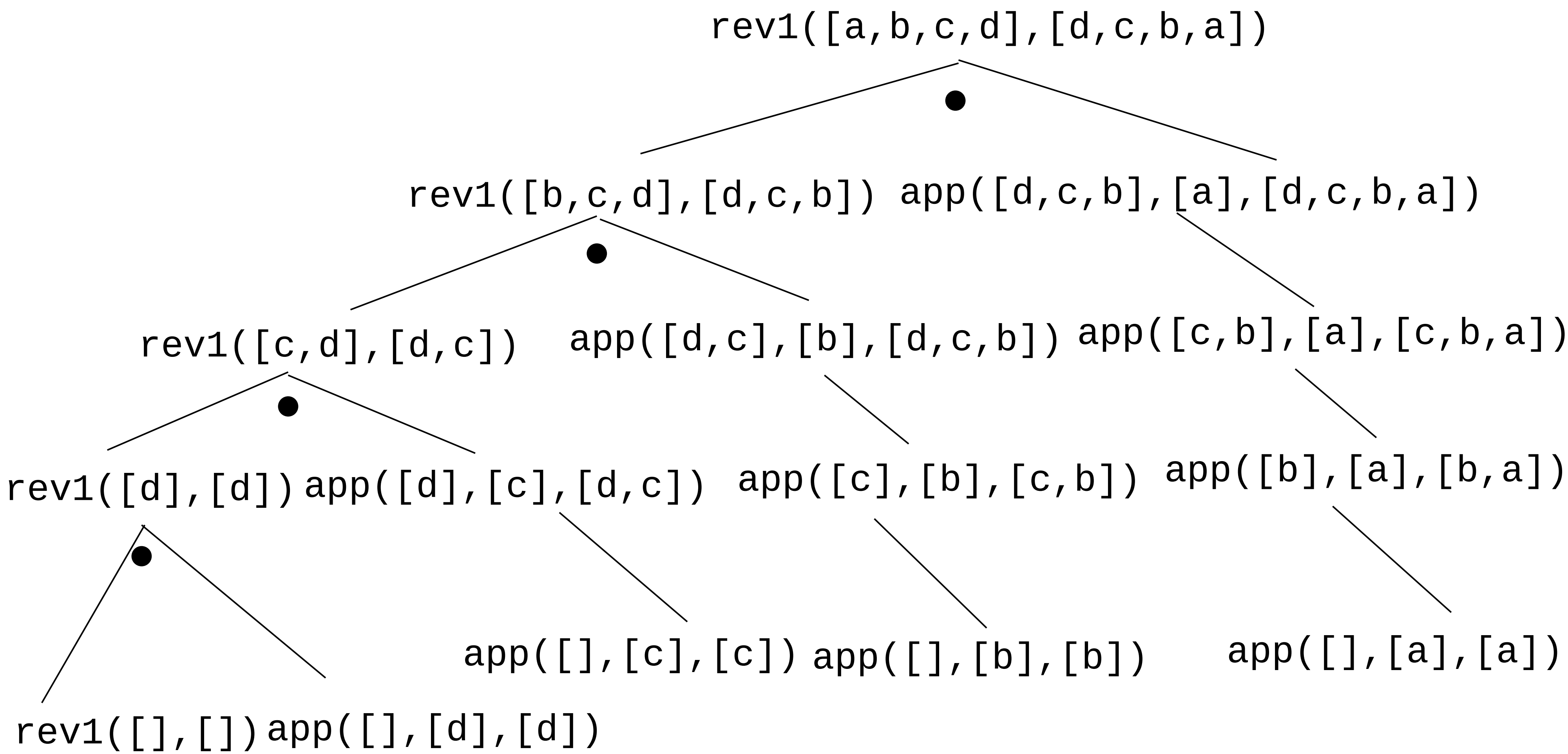
Prolog Lists — Reverse. . .

- `reverse1` works like this:
  1. Reverse the tail of the list.
  2. Append the head of the list to the reversed tail.
- `reverse2` is *linear* in the number of elements in the list.
- `reverse2` works like this:
  1. Use an accumulator pair `In` and `Out`
  2. `In` is initialized to the empty list.
  3. At each step we take one element (`X`) from the original list (`Z`) and add it to the beginning of the `In` list.
  4. When the original list (`Z`) is empty we instantiate the `Out` list to the result (the `In` list), and return this result up through the levels of recursion.

Prolog Lists — Reverse. . .

```
reverse1([], []).
reverse1([X|Q], Z) :-
   reverse1(Q, Y), append(Y, [X], Z).

reverse2(X, Y) :- reverse2(X, [], Y).
reverse2([X|Z], In, Out) :-
   reverse(Z, [X|In], Out).
reverse2([], Y, Y).
```

Reverse – Naive Reverse



Reverse – Smart Reverse

```
reverse2([a,b,c,d],D)   D=[d,c,b,a]

reverse2([a,b,c,d],[],D)

reverse2([b,c,d],[a],D)

reverse2([c,d],[b,a],D)

reverse2([d],[c,b,a],D)

reverse2([],[d,c,b,a],D)
```

Delete

Prolog Lists — Delete. . .

```
delete        from this     to yield
this one      list          this list

delete(X, L1, L2).
```

- **delete_one** — Remove the first occurrence.
- **delete_all** — Remove all occurrences.
- **delete_struct** — Remove all occurrences from all levels of a list of lists.

Prolog Lists — Delete. . .

```
?- delete_one(x, [a, x, b, x], D).
      D = [a, b, x]
?- delete_all(x, [a, x, b, x], D).
      D = [a, b]
?- delete_all(x, [a, x, b, [c, x], x], D).
      D = [a, b, [c, x]]
?- delete_struct(x, [a, x, [c, x], v(x)], D).
      D = [a, b, [c], v(x)]
```

Prolog Lists — Delete. . .

delete_one

1. If X is the first element in the list then return the tail of the list.
2. Otherwise, look in the tail of the list for the first occurrence of X.

Prolog Lists — Delete. . .

delete_all

1. If the head of the list is X then remove it, and remove X from the tail of the list.
2. If X is *not* the head of the list then remove X from the tail of the list, and add the head to the resulting tail.
3. When we're trying to remove X from the empty list, just return the empty list.

Prolog Lists — Delete...

- Why do we test for the recursive boundary case (`delete_all(X,[],[])`) last? Well, it only happens once so we should perform the test as few times as possible.
- The reason that it works is that when the original list (the second argument) is `[]`, the first two rules of `delete_all` won't trigger. Why? Because, `[]` does not match `[H|T]`, that's why!

Prolog Lists — Delete. . .

delete_struct

1. The first rule is the same as the first rule in `delete_all`.
2. The second rule is also similar, only that we descend into the head of the list (in case it should be a list), as well as the tail.
3. The third rule is the catch-all for lists.
4. The last rule is the catch-all for non-lists. It states that all objects which are not lists (atoms, integers, structures) should remain unchanged.

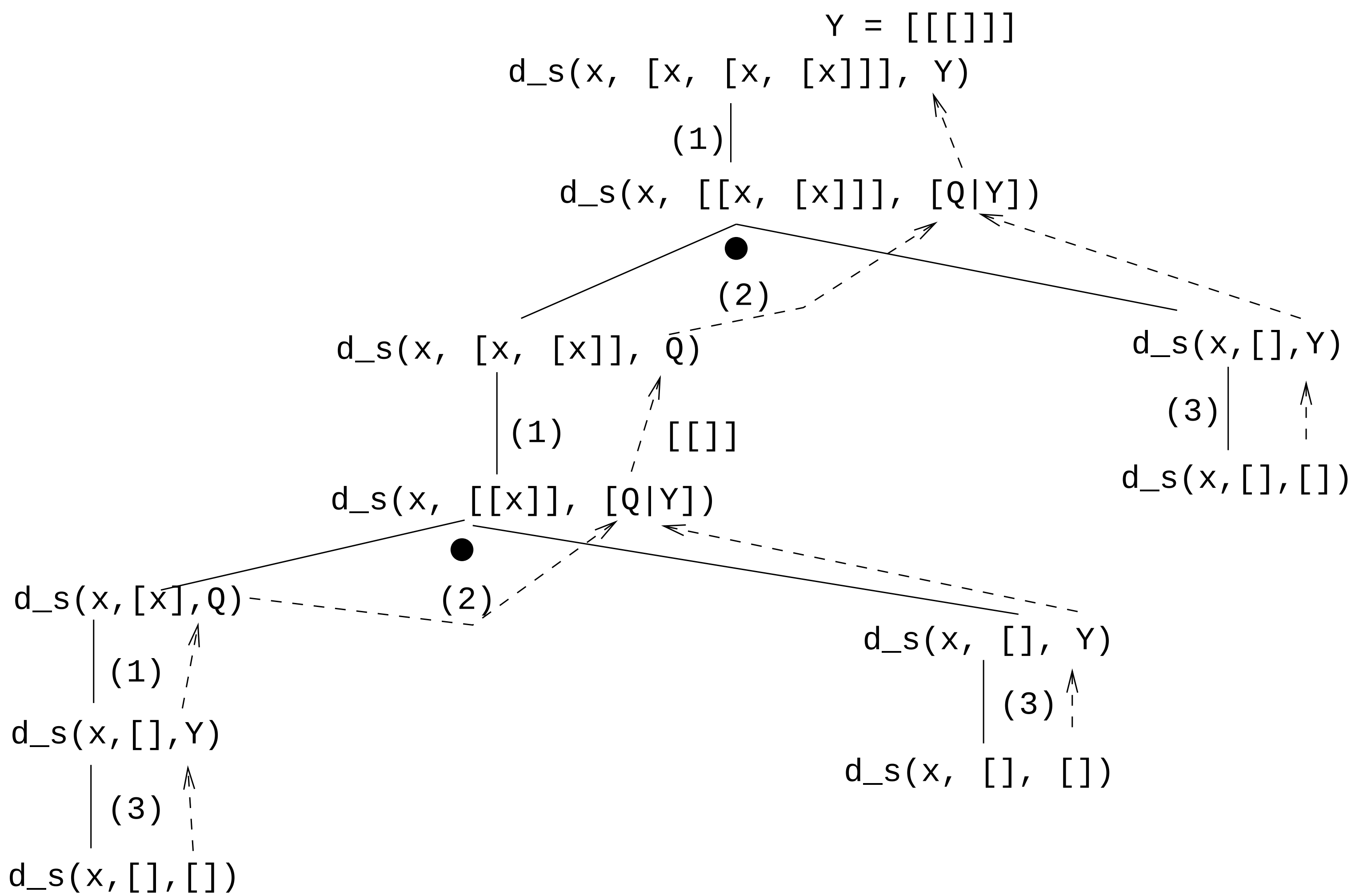
Prolog Lists — Delete. . .

```
delete_one(X,[X|Z],Z).
delete_one(X,[V|Z],[V|Y]) :-
      X \== V,
      delete_one(X,Z,Y).

delete_all(X,[X|Z],Y) :- delete_all(X,Z,Y).
delete_all(X,[V|Z],[V|Y]) :-
      X \== V,
      delete_all(X,Z,Y).
delete_all(X,[],[]).
```

Prolog Lists — Delete. . .

```
(1) delete_struct(X,[X|Z],Y) :-
      delete_struct(X, Z, Y).

(2) delete_struct(X,[V|Z],[Q|Y]):-
      X \== V,
      delete_struct(X, V, Q),
      delete_struct(X, Z, Y).

(3) delete_struct(X, [], []).
(4) delete_struct(X, Y, Y).
```

Prolog Lists — Delete. . .



Application: Sorting

Sorting – Naive Sort

```
permutation(X,[Z|V]) :-
    delete_one(Z,X,Y),
    permutation(Y,V).
permutation([],[]).

ordered([X]).
ordered([X,Y|Z]) :-
    X =< Y,
    ordered([Y|Z]).

naive_sort(X, Y) :-
    permutation(X, Y),
    ordered(Y).
```

Sorting – Naive Sort. . .

- This is an application of a Prolog cliche known as generate-and-test.

`naive_sort`

1. The `permutation` part of `naive_sort` generates one possible permutation of the input
2. The `ordered` predicate checks to see if this permutation is actually sorted.
3. If the list still isn't sorted, Prolog backtracks to the `permutation` goal to generate an new permutation, which is then checked by `ordered`, and so on.

Sorting – Naive Sort...

`permutation`

1. If the list is not empty we:
   1. Delete some element `Z` from the list
   2. Permute the remaining elements
   3. Add `Z` to the beginning of the list

   When we backtrack (ask `permutation` to generate a new permutation of the input list), `delete_one` will delete a different element from the list, and we will get a new permutation.
2. The permutation of an empty list is the empty list.

- Notice that, for efficiency reasons, the boundary case is put *after* the general case.

Sorting – Naive Sort. . .

`delete_one` Removes the first occurrence of `X` (its first argument) from `V` (its second argument).

- Notice that when `delete_one` is called, its first argument (the element to be deleted), is an uninstantiated variable. So, rather than deleting a specific element, it will produce the elements from the input list (+ the remaining list of elements), one by one:

```
?- delete_one(X,[1,2,3,4],Y).
X = 1, Y = [2,3,4] ;
X = 2, Y = [1,3,4] ;
X = 3, Y = [1,2,4] ;
X = 4, Y = [1,2,3] ;
no.
```

Sorting – Naive Sort. . .

The proof tree in the next slide illustrates `permutation([1,2,3],V)`. The dashed boxes give variable values for each backtracking instance:

First instance: `delete_one` will select `X=1` and `Y=[2,3]`. `Y` will then be permuted into `Y'=[2,3]` and then (after having backtracked one step) `Y'=[3,2]`. In other words, we generate `[1,2,3], [1,3,2]`.

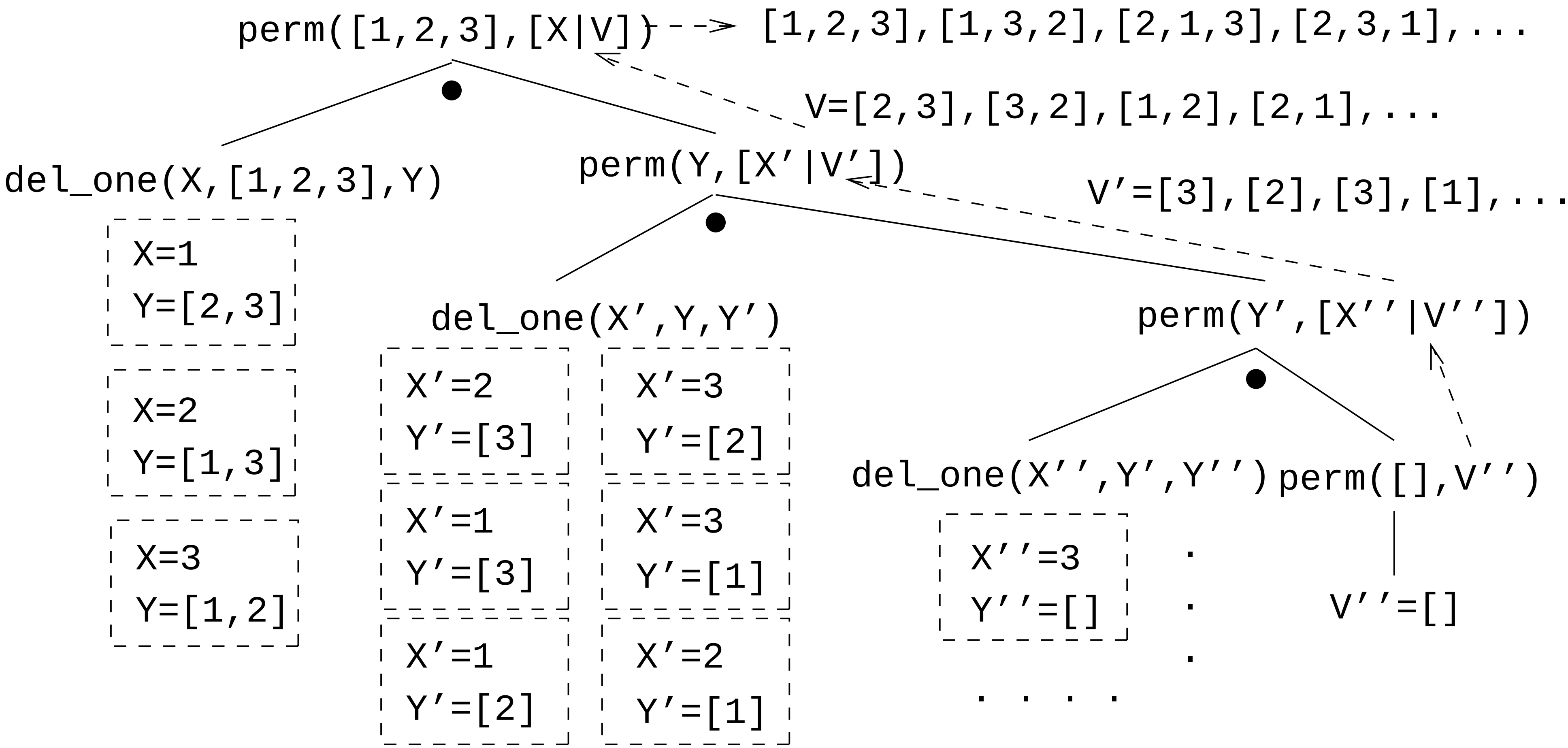
Second instance: We backtrack all the way back up the tree and select `X=2` and `Y=[1,3]`. `Y` will then be permuted into `Y'=[1,3]` and then `Y'=[3,2]`. In other words, we generate `[2,1,3], [2,3,1]`.

Sorting – Naive Sort. . .

Third instance: Again, we backtrack all the way back up the tree and select `X=3` and `Y=[1,2]`. We generate `[3,1,2]`, `[3,2,1]`.

```
?- permutation([1,2,3],V).
V = [1,2,3] ;
V = [1,3,2] ;
V = [2,1,3] ;
V = [2,3,1] ;
V = [3,1,2] ;
V = [3,2,1] ;
no.
```

Permutations



Sorting Strings

- Prolog strings are lists of ASCII codes.
- `"Maggie" = [77,97,103,103,105,101]`

```
aless(X,Y) :-
   name(X,X1), name(Y,Y1),
   alessx(X1,Y1).

alessx([],[_|_]).
alessx([X|_],[Y|_]) :- X < Y.
alessx([A|X],[A|Y]) :- alessx(X,Y).
```

Application: Mutant Animals

Mutant Animals

- From *Prolog by Example*, Coelho & Cotta.
- We're given a set of words (French animals, in our case).
- Find pairs of words where the ending of the first one is the same as the beginning of the second.
- Combine the words, so as to form new "mutations".

Mutant Animals. . .

1. Find two words, `Y` and `Z`.
2. Split the words into lists of characters. `name(atom, list)` does this.
3. Split `Y` into two sublists, `Y1` and `Y2`.
4. See if `Z` can be split into two sublists, such that the prefix is the same as the suffix of `Y` (`Y2`).
5. If all went well, combine the prefix of `Y` (`Y1`) with the suffix of `Z` (`Z2`), to create the mutant list `X`.
6. Use `name` to combine the string of characters into a new atom.

Mutant Animals. . .

```
mutate(M) :-
    animal(Y), animal(Z), Y \== Z,
    name(Y,Ny), name(Z,Nz),
    append(Y1,Y2,Ny), Y1 \==[],
    append(Y2, Z2, Nz), Y2 \== [],
    append(Y1,Nz,X), name(M,X).

animal(alligator).    /* crocodile*/
animal(tortue).       /* turtle   */
animal(caribou).      /* caribou  */
animal(ours).         /* bear     */
animal(cheval).       /* horse    */
animal(vache).        /* cow      */
animal(lapin).        /* rabbit   */
```

Mutant Animals. . .

```
?- mutate(X).
   X = alligatortue ;    /* alligator+ tortue */
   X = caribours ;       /* caribou  + ours */
   X = chevalligator ;   /* cheval   + alligator*/
   X = chevalapin ;      /* cheval   + lapin */
   X = vacheval          /* vache    + cheval */
```

Summary

Prolog So Far...

- Lists are nested *structures*
- Each list node is an object
  - with functor `.` (dot).
  - whose first argument is the head of the list
  - whose second argument is the tail of the list
- Lists can be split into head and tail using `[H|T]`.
- Prolog strings are lists of ASCII codes.
- `name(X,L)` splits the atom X into the string L (or vice versa).